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(54) Title: **Dental Element, especially a Tooth, consisting of a Metal  
Base and a Ceramic Cap, and Method for its Manufacture**

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(56) Prior-art documents considered in determining patentability:

Ger Pat 622.005

Ger Pat 847.571

US Pat 2.443.318

US Pat 2.861.010

US Pat 2.895.050

US Pat 2.897.595

US Pat 2.962.136

US Pat 3.031.737

J. Liebscher / F. Willert, "Technologie der  
Keramik" (ceramics technology), VEB-Verlag der  
Kunst, Berlin, 1955, pp. 330, 331

This invention relates to a dental element and in particular to a tooth consisting of a metal base and a preferably multi-layered ceramic cap produced from a powdered, feldspar-containing calcination product and a powdered fusion product containing a frit of feldspar and  $\text{Na}_2\text{O}$ - and, where appropriate,  $\text{MgO}$ -components.

The US patent 2.897.595 describes ceramic materials for dental elements composed of a maximum of 70 percent by weight of a vitreous substance with a high silica content and relatively free of other substances, and a powdered feldspar-containing flux. While this prior-art publication contains indications of how to adapt the thermal-expansion coefficients of different ceramic layers to one another, it gives no clue regarding the adaptation of the thermal expansion coefficient of the ceramic material to that of the dental metals that would be suitable for larger metal-to-ceramic interfaces, and merely discusses the fabrication of a hard ceramic material that is supposed to withstand the stress produced by strongly varying thermal expansion coefficients. That earlier theory, however, can be applied only when bonding a relatively large amount of ceramic material to a thin metal pin which is embedded in the ceramic material and which is not exposed to the effects of temperature changes, but it does not work in applications where the ceramic material and the metal are similar in volume.

It is the objective of this invention to introduce dental elements composed of a metal base and a ceramic cap similar in volume, where the ceramic material employed has a high thermal expansion coefficient ( $90$  to  $170 \times 10^{-7}/^\circ\text{C}$ ) which is adapted to that of the commonly used dental metals to where it is only slightly below that of the metal. Moreover, the thermal expansion coefficient of a particular ceramic material should remain virtually constant over the range from room temperature to the temperature of its plastic state. The conventional ceramic materials used in dentistry have had an expansion coefficient of only about  $75 \times 10^{-7}/^\circ\text{C}$ , limiting their compatibility to only a small group of dental metals.

Furthermore, the ceramic materials employed for producing dental elements per this invention, while having a thermal expansion coefficient that is adapted to that of all common dental metals, are also designed to have a wide melting range, permitting their adaptation, as substances with a high, medium or low melting point, for a variety of applications (material for sealing dental surfaces, material for repairs, or material for reshaping to be fused onto a low-melting metal base).

Finally, it is necessary to obtain a good match of the thermal expansion coefficients of the individual ceramic materials used in a composite dental element such as a tooth, i.e. the body material, a transparent material for the cutting edges and tips and an opaque ceramic material for covering the metal.

A drawback of the conventional ceramic materials used in Germany lies in the difficulty of grinding the ceramic close to the metal base without the highly stressed ceramic breaking at the boundary surface between it and the metal.

It is an essentially traditional process to produce the ceramic part for artificial teeth from at least two layers of different ceramic materials. The body material makes up the main part of the artificial tooth. Translucent ceramic which melts into a relatively clear, glass-like material is used for making the cutting edges and tips of the artificial tooth translucent and, where appropriate, to mitigate the opacity of the body enamel. Opaque ceramic material is used for covering a dark metal base especially in the case of a thin body material. Apart from that, opaque material is best suited for the overall color appearance of the artificial ceramic tooth. It is also an established practice to enhance the hardness of artificial teeth composed of different ceramic materials by matching the thermal expansion coefficients of the individual materials with a temperature-coefficient gradient in the direction of the metal core periphery.

For that type of layering the ceramic materials of this invention can be used with particularly good success.

Specifically, the invention relates to a dental element of the type first above described and characterized in that the ceramic material of the cap is composed of the following:

SiO <sub>2</sub>	57.8 to 73.0 % by weight
Al <sub>2</sub> O <sub>3</sub>	11.1 to 17.1 % by weight
CaO	0.1 to 2.6 % by weight
MgO	0.1 to 1.8 % by weight
Na <sub>2</sub> O	1.9 to 9.6 % by weight
K <sub>2</sub> O	6.35 to 19.3 % by weight
Li <sub>2</sub> O	0.0 to 5.0 % by weight

where the expansion coefficient of the ceramic material selected is only slightly below that of the metal base, and the ceramic material is constituted of a homogeneous, fired mixture of

- (a) a vitreous, pulverulent calcination product of a feldspar-containing mineral with not less than 80% orthoclase to which, where appropriate, a K<sub>2</sub>O- and/or Li<sub>2</sub>O-containing substance is added, and
- (b) a powdered fusion product containing not less than 30% natural feldspar and a material constituted of SiO<sub>2</sub> (5 to 70 % by weight), Al<sub>2</sub>O<sub>3</sub> (0 to 5 % by weight), Na<sub>2</sub>O (0 to 16.5 % by weight), CaO (0 to 5 % by weight) and MgO (0 to 3.5 % by weight).

A ceramic material of this composition has a thermal expansion coefficient of between 90 and 170 x 10<sup>-7</sup>/°C from room temperature up to the temperature of the plastic state.

In an advantageously enhanced version of the object of this invention, the dental elements can be produced with a high-melting ceramic material which is characterized in that the ceramic material is preferably composed of

SiO <sub>2</sub>	63 to 73 % by weight
Al <sub>2</sub> O <sub>3</sub>	14 to 17 % by weight
CaO	0.5 to 1.5 % by weight
MgO	0.2 to 0.8 % by weight
Na <sub>2</sub> O	2 to 3.5 % by weight
K <sub>2</sub> O	11 to 15 % by weight

and a homogeneous calcined i.e. fired mixture of

- (a) a vitreous, pulverulent calcination product of a feldspar and about 80% orthoclase with an admixture to the latter, where appropriate, of 1 to 5% K<sub>2</sub>CO<sub>3</sub> or a comparable amount of a powdered fusion product consisting of K<sub>2</sub>O and SiO<sub>2</sub> at a 2:5 weight ratio or a powdered frit with about 50% SiO<sub>2</sub>, 7% Al<sub>2</sub>O<sub>3</sub>, 10% CaO, 5% MgO, 8% Na<sub>2</sub>O and 20% K<sub>2</sub>O at a 15:85 weight ratio (frit:orthoclase feldspar) and
- (b) a powdered fusion product consisting of 70 to 95% natural feldspar and 5 to 30% SiO<sub>2</sub>, preferably of about 75% natural feldspar and about 25% SiO<sub>2</sub>

with the ratio between the components (a) and (b) being about 1:1 to about 9:1.

The high-melting ceramic materials used in the enhanced version of the invention melt above 982°C and excel by virtue of their resistance to thermal shocks, to mechanical impact as well as to erosion by oral fluids. Existing high-melting ceramic materials have a thermal expansion coefficient of about 75 x 10<sup>-7</sup>/°C in the range from room temperature to the plastic-state temperature. When they are fused to dental metals with the nearest expansion coefficients, these being iridium-platinum alloys (about 100 x 10<sup>-7</sup>/°C), the ceramic cap develops a high level of

mechanical stress and breakage can occur even with only minor additional pressure.

The low-melting ceramic materials, also used within the scope of this invention, having melting points below about 980 to 900°C, can serve as additives, repair or reshaping materials and modifiers for high-melting ceramics for fusion onto low-melting bases such as gold alloys. In this area as well, the difference in the expansion coefficients of the conventional ceramic materials has been a problem. Besides, the conventional low-melting ceramic materials contain borax which tends to lead to an undesirable level of solubility and poor color characteristics.

Other dental metals such as palladium, gold and the passive nonprecious base metals have even higher expansion coefficients than the iridium-platinum alloys, which leads to even greater stress patterns in the case of conventional ceramic materials.

It is for this reason that, so far, the dental industry has employed ceramic materials primarily for cosmetic repairs, especially on front teeth, using gold crowns and bridges for the rest.

The ceramic materials employed according to this invention constitute a technical innovation insofar as they can be used for producing dental elements which leave no metal visibly exposed in the mouth, thus preserving a natural appearance. Moreover, these ceramic materials are substantially more wear-resistant, stronger and more color-fast than the dental plastics used to date.

With this invention it is possible to provide patients with permanent dentures consisting of complete metal bridges with a fused-on ceramic material in place of removable bridges, which prevents many of the causes of periodontoclasia while providing a masticatory surface that offers the function of natural teeth. Of course, where necessary, the invention can be applied in the production of removable dentures as well.

The metals that can be used for the metal bases of the dental elements according to this invention include the precious metals already commonly used in prosthodontics such as gold, silver, platinum etc., as well as the passive base metals such as austenitic stainless steels, high-cobalt chromium alloys etc. The nonprecious base metals oxidize strongly at the melting temperatures of the ceramic material (around 800 to 1315°C). The oxides do not adhere, and the oxides of cobalt, chromium and nickel are strong chromophores which cause discoloration of the ceramic. Other precious metals such as gold/silver alloys, having relatively low melting points, can only in their molten state be fused to high-melting ceramic materials.

For dental elements according to this invention, precious metals and passive nonprecious base metals can be employed as a base for the ceramic cap even when the melting temperature of the metal is lower than that of the ceramic material, provided the formation of nonadhering and discoloring oxides is avoided.

This invention is explained in more detail in the following description with reference to examples of dental elements illustrated in the drawings in which –

Fig. 1 is a frontal view of a ceramic-capped, metal-core, bridge-mounted molar tooth per this invention;

Fig. 2 is a section view of that tooth along the cheek-to-tongue line;

Fig. 3 shows that tooth as seen from the tongue;

Fig. 4 is a mesio-distal cross section of that tooth;

Fig. 5 is a cheek-to-tongue cross-sectional view of a jacket crown per this invention, mounted on a natural tooth that has been prepared for capping;

Fig. 6 is a cheek-to-tongue cross-sectional view of a bridge-mounted molar tooth in which a metal-based retaining element has been molded into the ceramic cap;

Fig. 7 is a mesio-distal cross section of that tooth with solderable inserts; and

Fig. 8 is a graph showing the ratios of the ceramic-material components which must be observed to obtain a finished ceramic product with a predefined expansion coefficient.

First, a description of the method for producing the components for high-melting dental ceramic materials.

#### Component # 1

The first component is produced from a frit and a high-orthoclase feldspar for instance in a theoretically calculated combination of 16.17 parts albite and 83.83 parts orthoclase, the composition being as follows:

High-orthoclase feldspar		Frit	
SiO <sub>2</sub>	55.6 %	SiO <sub>2</sub>	50 %
Al <sub>2</sub> O <sub>3</sub>	18.4 %	Al <sub>2</sub> O <sub>3</sub>	7 %
Na <sub>2</sub> O	2.6 %	Na <sub>2</sub> O	8 %
K <sub>2</sub> O	13.2 %	K <sub>2</sub> O	20 %
CaO	0.1 %	CaO	10 %
MgO	0.1 %	MgO	5 %
	<u>100.0 %</u>		<u>100 %</u>

A mixture of 15 percent by weight of the powdered frit with 85% of powdered feldspar produces the following analysis:

SiO <sub>2</sub>	63.40 % by weight
Al <sub>2</sub> O <sub>3</sub>	16.70 % by weight
CaO	1.50 % by weight
MgO	0.80 % by weight
Na <sub>2</sub> O	3.41 % by weight
K <sub>2</sub> O	<u>14.19 % by weight</u>
	100.00 % by weight

The mixture is baked at about 1315°C (about cone penetration 12) for 2 hours or until the mixture has transitioned into the vitreous state. It is then cooled and pulverized until about 2 to 5% remain on a screen with an effective mesh of about 0.074 mm. Its melting point is about 1093°C. This is component #1. Lowering the percentage of the powdered frit results in a higher melting point for the ceramic material and in a lower expansion coefficient.

#### Component # 2

This component is made up of a mixture of about 75% ordinary clear feldspar and about 25% silica. The mixture has the following composition:

SiO <sub>2</sub>	73.50 % by weight
Al <sub>2</sub> O <sub>3</sub>	14.40 % by weight
CaO	0.25 % by weight
MgO	0.10 % by weight
Na <sub>2</sub> O	1.75 % by weight
K <sub>2</sub> O	<u>10.00 % by weight</u>
	100.00 % by weight

The mixture is vitrified at about 1315°C (roughly cone penetration 12) for about 2 hours or until no free silica is left, then cooled and pulverized in the same way as above. Its melting point is about 1315°C. This is component #2. Lowering the percentage of silica results in a lower melting point of the finished ceramic material. For example, if only 15% silica is added in producing component #2, the melting point will be around 1260°C.

#### First Example

##### High-melting Ceramic Material No. 1

For arriving at a high-melting ceramic material, a mixture consisting of even parts of powdered component #1 and powdered component #2 is produced, its composition being as follows:

SiO <sub>2</sub>	68.45 % by weight
Al <sub>2</sub> O <sub>3</sub>	15.55 % by weight
CaO	0.90 % by weight
MgO	0.45 % by weight
Na <sub>2</sub> O	2.55 % by weight
K <sub>2</sub> O	<u>12.10</u> % by weight
	100.00 % by weight

This is a special, high-melting, strongly expanding ceramic material with an expansion coefficient of just below  $125 \times 10^{-7}/^{\circ}\text{C}$  and a melting range in the neighborhood of 1150°. After two baking cycles over several stages, without changing its expansion characteristics, this ceramic material can be fused onto a palladium-metal alloy base having an expansion coefficient of  $125 \times 10^{-7}/^{\circ}\text{C}$  and composed of the following:

Palladium	93.5 % by weight
Ruthenium	<u>6.5</u> % by weight
	100.0 % by weight

##### Component # 1a (alternative)

Another high-melting dental ceramic material is obtained by first baking a high-orthoclase feldspar, for instance one composed of 16.17 parts albite and 83.83 parts orthoclase, at about 1315°C for about 2 hours or until all material has transitioned into the vitreous state, then cooling it and pulverizing it as described above. The product is an alternative to component #1 for producing a ceramic material per this invention.

It is possible to add to the high-orthoclase feldspar 1 to 5% of potassium in the form of potash in the event there is not enough orthoclase. In lieu of potash, a powdered fusion product consisting of K<sub>2</sub>O at about 1 part by weight and SiO<sub>2</sub> at about 2½ parts by weight may be added.

A mixture of component #1a and the original component #2 is well suited to the purpose discussed and, with identical component quantities, it will result in a ceramic material of perfectly satisfactory aesthetic and physical properties, with a melting range around 1150°C and an expansion coefficient of just below  $125 \times 10^{-7}/^{\circ}\text{C}$ . This material can be fused to the palladium alloy of the first example described above.

## Second Example

### High-melting Ceramic Material No. 2

The ratio between component #1 and component #2 is so selected as to arrive at an expansion coefficient that is higher than in the first example. For this material, 90% of component #1 and 10% of component #2 may be used. The composition of the material is as follows:

SiO <sub>2</sub>	65.42 % by weight
Al <sub>2</sub> O <sub>3</sub>	16.24 % by weight
CaO	1.25 % by weight
MgO	0.66 % by weight
Na <sub>2</sub> O	3.07 % by weight
K <sub>2</sub> O	13.36 % by weight
	<u>100.00 % by weight</u>

The expansion coefficient will be slightly below  $165 \times 10^{-7}/^{\circ}\text{C}$ .

This ceramic material can be fused to a chromium-cobalt base having an expansion coefficient of  $165 \times 10^{-7}/^{\circ}\text{C}$  and the following composition:

Chromium	27.00 % by weight
Molybdenum	6.00 % by weight
Nickel	2.00 % by weight
Iron	1.00 % by weight
Carbon	0.25 % by weight
Manganese	0.60 % by weight
Silicon	0.60 % by weight
Cobalt	<u>62.55 % by weight</u>
	100.00 % by weight

With cobalt-chromium alloys, very durable, inexpensive, relatively low-weight dental elements can be produced, although the process of fusing the ceramic material onto the cobalt-chromium alloy requires a different fusion technique. The fusion is preferably performed in a high vacuum to prevent oxidation since the oxides of cobalt, chromium, nickel and iron would tend to discolor the ceramic material. Also, the oxides often have no adhesive strength and tend to destroy the solid bond at the interface between the ceramic and the metal. Apart from vacuum fusion for preventing oxidation, there are other acceptable methods, for instance fusion in a reducing or neutral atmosphere. Oxidation can also be avoided by means of a thick coat of a nonoxidizing metal such as gold which can be diffused into the cobalt-chromium alloy under vacuum at high temperatures.

Apart from fusing the ceramic onto the metal as illustrated in fig. 2, 4 and 5, the ceramic jacket proper may be molded in the desired shape and provided with appropriate openings for casting-in a metal core as depicted in fig. 7. This is another way to prevent oxidation and discoloration.

It is equally possible within the limits indicated to use different quantitative ratios of the components #1 and #2, with different expansion coefficients and different melting ranges. The graph in fig. 8 shows the component ratios and corresponding coefficients of expansion. Indeed, the quantitative ratios fluctuate between 25% for component #1 and ((illegible, 8<sup>th</sup> line from bottom, column 7)) % for component #2 for ceramic materials

having a low expansion coefficient (about  $90 \times 10^{-7}/^{\circ}\text{C}$ ) and a melting range of around  $1315^{\circ}\text{C}$  ...*((text clipped, 5<sup>th</sup> line from bottom, column 7))* ... 100% of component #1 for ceramic materials having a high expansion coefficient (about  $170 \times 10^{-7}/^{\circ}\text{C}$ ) and a melting range around  $1093^{\circ}\text{C}$ .

The high-melting dental ceramic materials used according to this invention, with expansion coefficients of between  $90$  and  $170 \times 10^{-7}/^{\circ}\text{C}$  and melting points of between  $1315$  and  $1093^{\circ}\text{C}$  feature compositions in the following approximate ranges:

SiO <sub>2</sub>	65.0 to 73.0 % by weight
Al <sub>2</sub> O <sub>3</sub>	14.0 to 17.0 % by weight
CaO	0.5 to 1.5 % by weight
MgO	0.3 to 0.8 % by weight
Na <sub>2</sub> O	2.0 to 3.5 % by weight
K <sub>2</sub> O	11.0 to 15.0 % by weight

The following describes ceramic materials with medium-range melting points. These ceramic materials may be produced in similar fashion as the high-melting ceramic materials, for instance by mixing component #1 with a component #3, substituting component #2.

Component #3 can be produced from feldspar and a frit as follows:

	High-Orthoclase Feldspar (as in component #1)	Frit
SiO <sub>2</sub>	65.6 %	70.09 %
Al <sub>2</sub> O <sub>3</sub>	18.4 %	5.00 %
Na <sub>2</sub> O	2.6 %	16.50 %
K <sub>2</sub> O	13.2 %	-----
CaO	0.1 %	5.00 %
MgO	<u>0.1 %</u>	<u>3.50 %</u>
	100.0 %	100.00 %

A mixture of these two powdered substances at a 1:1 ratio is melted for 2 hours at about  $1204^{\circ}\text{C}$ , resulting in component #3 with the following composition:

#### Component # 3

SiO <sub>2</sub>	67.80 % by weight
Al <sub>2</sub> O <sub>3</sub>	11.70 % by weight
Na <sub>2</sub> O	9.55 % by weight
K <sub>2</sub> O	6.60 % by weight
CaO	2.55 % by weight
MgO	<u>1.80 % by weight</u>
	100.00 % by weight

This fusion product will melt at about  $900^{\circ}\text{C}$ .



### Third Example

#### Ceramic Material No. 1 with a medium-range melting point

A ceramic material with a medium melting range can be obtained by combining the powdered component #1 with the powdered component #3 at a 1:1 ratio. The final composition of this ceramic material is as follows:

SiO <sub>2</sub>	65.60 % by weight
Al <sub>2</sub> O <sub>3</sub>	14.20 % by weight
Na <sub>2</sub> O	6.47 % by weight
K <sub>2</sub> O	10.40 % by weight
MgO	1.30 % by weight
CaO	<u>2.03</u> % by weight
	100.00 % by weight

This ceramic material will melt at about 970°C and has an expansion coefficient of  $125 \times 10^{-7}/^{\circ}\text{C}$ . It is suitable for use in the application described in the first example.

By varying the ratio between component #1 and component #3, different expansion coefficients and melting-point ranges can be obtained in a manner similar to the second example, as indicated below.

### Fourth Example

#### Ceramic Material No. 2 with a medium-range melting point

A mixture consisting of 7 parts by weight of component #1 and 3 parts by weight of component #3 will have an expansion coefficient of  $140 \times 10^{-7}/^{\circ}\text{C}$  and a melting range around 954°C. This mixture can be fused onto an alloy consisting of 80% gold and 20% platinum. The alloy has an expansion coefficient of about  $140 \times 10^{-7}/^{\circ}\text{C}$  and a melting temperature of about 1204°C. A combination of components #1 and #3 along the quantitative curves per fig. 8 will show that the expansion coefficients fluctuate in essentially the same way as in the case of components #1 and #2. The melting points are in the range between about 1093°C (100% component #1) and 900°C (100% component #3 with an expansion coefficient of about  $80 \times 10^{-7}/^{\circ}\text{C}$ ).

### Component # 4

(as an alternative to component # 1)

An example of an alternative to component #1 (produced under inclusion of 10% potassium carbonate and 90% feldspar with a high orthoclase content) may have the following composition:

SiO <sub>2</sub>	61.00 % by weight
Al <sub>2</sub> O <sub>3</sub>	17.10 % by weight
Na <sub>2</sub> O	2.37 % by weight
K <sub>2</sub> O	19.31 % by weight
CaO	0.11 % by weight
MgO	<u>0.11</u> % by weight
	100.00 % by weight

The melting temperature of component #4 (at about 1066°C) is lower than that of component #1.

Using lithium oxide ( $\text{Li}_2\text{O}$ ) will lead to similar results as the use of potash. It can be added to the feldspar either as a frit or in the form of lithium carbonate.

In terms of its weight relation, lithium oxide is twice as effective as  $\text{K}_2\text{O}$ . In lieu of the specified quantity of potash half that amount of lithium oxide will suffice if one wants to correspondingly lower the melting points and increase the thermal expansion coefficients.

Lithium carbonate in an amount for instance of 5% is added to a feldspar with a high orthoclase content (16.17% albite and 83.83 orthoclase) and an oxide composition essentially as follows:

$\text{SiO}_2$	65.60 % by weight
$\text{Al}_2\text{O}_3$	18.40 % by weight
$\text{Na}_2\text{O}$	2.55 % by weight
$\text{K}_2\text{O}$	13.20 % by weight
CaO and MgO	<u>0.25</u> % by weight
	100.00 % by weight

This is fused at 1204°C for 2 hours until vitrification sets in, resulting in the following composition:

Component # 5  
(as an alternative to component # 1)

$\text{SiO}_2$	64.30 % by weight
$\text{Al}_2\text{O}_3$	18.10 % by weight
$\text{Na}_2\text{O}$	2.50 % by weight
$\text{K}_2\text{O}$	12.90 % by weight
CaO and MgO	0.20 % by weight
$\text{Li}_2\text{O}$	<u>2.00</u> % by weight
	100.00 % by weight

This component #5 has a low melting point at about 982°C and an expansion coefficient of more than  $170 \times 10^{-7}/^\circ\text{C}$ .

Component #5 is combined with component #3 at a 50:50 ratio which results in an alternative ceramic material with a medium-range melting point and the following composition:

Fifth Example  
Ceramic Material No. 3  
with a medium-range melting point

$\text{SiO}_2$	65.7 % by weight
$\text{Al}_2\text{O}_3$	15.0 % by weight
$\text{Na}_2\text{O}$	6.0 % by weight
$\text{K}_2\text{O}$	9.3 % by weight
CaO and MgO	2.0 % by weight
$\text{Li}_2\text{O}$	<u>2.0</u> % by weight
	100.0 % by weight

This material has an expansion coefficient of about  $140 \times 10^{-7}/^{\circ}\text{C}$  and a melting temperature of about  $954^{\circ}\text{C}$ . It is also suitable for fusion onto a gold-alloy base as in the fourth example.

The following describes low-melting ceramic materials with melting temperatures of between about  $900$  and  $982^{\circ}\text{C}$ . Similar methods may be used to produce these materials. They include two new components, # 6 and # 7.

Component #6 is produced using 90 parts feldspar of component #1, 5 parts frit of component #1, and 5 parts lithium carbonate. The mixture is vitrified at about  $1204^{\circ}$  for 2 hours or until a vitreous state is obtained. The material is subsequently ground to a powder, to where 95% will pass through a screen with an effective mesh size of about  $0.074$  mm.

The constituents of component #6 are as follows:

$\text{SiO}_2$	63.41 % by weight
$\text{Al}_2\text{O}_3$	17.45 % by weight
$\text{K}_2\text{O}$	13.28 % by weight
$\text{Na}_2\text{O}$	2.84 % by weight
$\text{Li}_2\text{O}$	2.06 % by weight
$\text{CaO}$	0.61 % by weight
$\text{MgO}$	<u>0.35 % by weight</u>
	100.00 % by weight

((text clipped, bottom of column 10)) ... a thermal expansion coefficient of about  $170 \times 10^{-7}/^{\circ}\text{C}$  and a melting point of about  $900^{\circ}\text{C}$ .

The component #7 for low-melting ceramic materials is produced from 30 parts feldspar (as in the production of component #1) and 70 parts of a frit of the following composition:

$\text{SiO}_2$	70.0 % by weight
$\text{Al}_2\text{O}_3$	5.0 % by weight
$\text{Na}_2\text{O}$	16.5 % by weight
$\text{CaO}$	5.0 % by weight
$\text{MgO}$	<u>3.5 % by weight</u>
	100.0 % by weight

This mixture of frit and feldspar is baked at  $1204^{\circ}\text{C}$  for 2 hours or until a vitreous state is obtained. The material is subsequently ground to a powder, to where 95% will pass through a screen with an effective mesh size of about  $0.074$  mm.

The component #7 has a thermal expansion coefficient of about  $85 \times 10^{-7}/^{\circ}\text{C}$  and a melting point of about  $982^{\circ}\text{C}$ . Its composition is as follows:

#### Component # 7

$\text{SiO}_2$	68.68 % by weight
$\text{Al}_2\text{O}_3$	9.02 % by weight
$\text{K}_2\text{O}$	3.96 % by weight
$\text{Na}_2\text{O}$	12.33 % by weight
$\text{CaO}$	3.53 % by weight
$\text{MgO}$	<u>2.48 % by weight</u>
	100.00 % by weight

### Sixth Example Low-melting Ceramic Material

A mixture of 6 parts by weight of component #6 and 4 parts by weight of component #7 produces a low-melting ceramic material (melting point about 900°C) with the following composition:

SiO <sub>2</sub>	65.518 % by weight
Al <sub>2</sub> O <sub>3</sub>	14.078 % by weight
K <sub>2</sub> O	9.552 % by weight
Na <sub>2</sub> O	6.636 % by weight
Li <sub>2</sub> O	1.236 % by weight
CaO	1.778 % by weight
MgO	<u>1.202</u> % by weight
	100.000 % by weight

This low-melting ceramic material has a thermal expansion coefficient of about  $130 \times 10^{-7}/^{\circ}\text{C}$ . It is suitable for use as an additive to, or substitute for, high- or medium-melting ceramic materials of the first and third examples.

By varying the ratio between the components #6 and #7, different thermal expansion coefficients and melting-point ranges can be obtained.

The low-melting dental ceramic materials used according to this invention, with expansion coefficients of between 80 and  $170 \times 10^{-7}/^{\circ}\text{C}$  and melting points in the range from 900 to 1066°C are ... ((text clipped, bottom of column 11))...

SiO <sub>2</sub>	61.0 to 67.8 % by weight
Al <sub>2</sub> O <sub>3</sub>	17.1 to 11.7 % by weight
CaO	0.1 to 2.6 % by weight
MgO	0.1 to 1.8 % by weight
Na <sub>2</sub> O	2.37 to 9.6 % by weight
K <sub>2</sub> O	19.3 to 6.7 % by weight

If lithium oxide (Li<sub>2</sub>O) is used in components #5 and #6, that amount of lithium oxide should be included in the above composition at a concentration of between 0 and 5%, with a corresponding reduction of the concentration of the remaining constituents by 0 to 5 %.

Ceramic materials with an expansion coefficient of 80 to  $170 \times 10^{-7}/^{\circ}\text{C}$  and a melting point in the range from about 900 to 1315°C are composed as follows:

SiO <sub>2</sub>	61.0 to 73.0 % by weight
Al <sub>2</sub> O <sub>3</sub>	11.7 to 17.1 % by weight
K <sub>2</sub> O	6.7 to 19.3 % by weight
Na <sub>2</sub> O	2.0 to 9.6 % by weight
CaO	0.1 to 2.6 % by weight
MgO	0.1 to 1.8 % by weight

If lithium oxide (Li<sub>2</sub>O) is used, in quantities between 0 and 5%, in producing these ceramic materials, the above minimum values for the other constituents will be reduced correspondingly.

These dental ceramic materials can be applied as glazing agents without losing any of the fine contours and features. This is possible, however, only if at the glazing temperature the materials are in a state of high viscosity.

The ceramic materials are so formulated that their expansion coefficient is slightly below that of the metal base. This is generally known to apply pressure to the ceramic, a compressive force which it withstands best, in contrast to tensile stress against which ceramic materials are vulnerable. Depending on the desired opacity and color, clay and coloring oxides may be added in small amounts from 0 to 5 % by weight.

The dental elements produced in accordance with this invention permit the use of metal bases which would oxidize slightly at high melting temperatures. This is due to the fact that when, at plastic-state temperatures (about 870°C), the base metals are quickly cast into the high-melting ceramic, the time in which the metal is heated and exposed is too short for any oxidation to take place that would discolor the ceramic material.

With reference to the attached figures 1 to 7, the following description explains the structure and the fabrication of an artificial tooth and a jacket crown according to this invention.

The artificial bridge-mounted molar tooth 14 depicted in fig. 1 to 4 is set on the gum 16. It has an occluding masticatory surface 10 and a metal core 12 which serves as a base for the ceramic cap 18.

For capping existing teeth the surface of the base should preferably match that of the natural tooth. ... ((original text clipped, bottom of column 12))... entire surface connected with the ceramic cap 18. Due to the fact that the expansion coefficient of the metal approximately corresponds to that of the ceramic material, it is now possible for the first time to use a relatively thin ceramic cap which is free of both internal stress and excessive compression.

In producing the cap for the molar tooth 14 (fig. 2), the site at which the metal core 12 is inserted may include a space 20 which may be kept narrow in order to keep both the weight and the cost of the metal down while providing a better bond with the ceramic cap 18. The metal core (fig. 4) features lobes 22 which extend all the way to the surface and which constitute the metal-to-metal contacts with neighboring support teeth.

The jacket crown 30 illustrated in fig. 5 includes an outer ceramic cap 32 which has been fused to the metal core 34. The dental stump 36 which sits in the gingiva (39) has been ground to a truncated cone. A 5° taper is sufficient.

The crown 30 is set on a wax impression (not shown) of the tooth. The wax impression is subsequently filled with molten gold or other suitable metal 38 which, at the edge of the dental stump 36, makes close contact with the gingiva. The crown 30, with its metal core 34, thus establishes a perfect fit on the stump 36 on which it is mounted via a bonding material 38.

The new teeth are produced in a mold which determines the outer contours and size of the ceramic tooth to be fabricated. A metal core of the right type and size is inserted in the mold and properly positioned in conventional fashion. The ceramic material to be filled in contains a binder, for instance starch and water, which puts the ceramic material in a moldable state and helps solidify it when the mold is removed and the teeth are placed in the oven in which the ceramic and the metal are fused together.

For producing high-melting ceramic dental parts the teeth are kept in the oven for about half an hour at about 1093°C (cone penetration 02) or for a few minutes at around 1177°C.

The bridge-mounted molar tooth illustrated in fig. 6 and 7 includes a ceramic cap 40 with a hollow space 41. Underneath position 46, the mesial and distal surfaces of the ceramic cap 40 are provided with passages which are filled with the metal of the metal body 48 or with some other metal that can be soldered to the latter, thus allowing for a connection with neighboring teeth.

To produce the ceramic cap 40, it is baked in the form of a tooth with the hollow space 41. Then, at a temperature at which the ceramic material is in the plastic state which in the case of high-melting ceramic materials is around 870°C, the metal can be poured directly into that hollow space. In this case, the hollow space of the dental cap is filled with wax, the cap is then covered with molding batch material, the wax is burned out and the metal is introduced by the centrifugal-casting or other suitable method. To that end the metal is heated to above its melting point which in the case of the cobalt-chromium alloy would be about 1427°C ... ((text clipped, bottom of column 13)) ... heated to the plastic-state temperature, i.e. about 870°, before the metal is cast. At this temperature the cap, being in the plastic state, can withstand an extreme thermal shock without breaking. It is subsequently allowed to slowly cool to room temperature.

The inside of the ceramic may be given a suitably textured surface, for instance as indicated by 50 in fig. 7, for obtaining additional mechanical contact by means of a serration in which the metal can penetrate for an enhanced, stronger bond. Before the metal body 48 is poured, the inside surface of the ceramic cap 40 may be provided for instance with baked-in metal particles such as gold chips 52 for enhancing the bond between the ceramic and the metal core.

If metals such as iron, cobalt, nickel and/or chromium are to be used for the metal body 48, the lateral sections 54 at the mesial and distal end surfaces of the passages underneath position 46 may first be produced from gold solder or other solderable metal. The nonprecious base-metal parts of the metal body 48 are then fused to the lateral sections 54 whose exposed precious-metal surfaces can be soldered to the neighboring tooth. The opening at which the nonprecious metals are poured into the tooth are then closed with a suitable ceramic plug 56 which is fused on, leaving the gingival tissue 58 in contact with ceramic only.

This invention makes it possible to produce dental bridges with ceramic-capped, metal-reinforced teeth where no metal is externally visible, which are of an aesthetically pleasing color of the right hue level and with an excellent gloss, which are very strong, biocompatible and structurally simple, which are easily soldered together and which are formed in a way as to provide maximum support for the ceramic, thus minimizing any risk of breakage.

For the first time, based on this invention, the dentist is enabled to reliably produce all or any part of the dentures from ceramic materials. The patient can thus fully benefit from the advantages offered by ceramic materials over the traditional acrylic-resin dentures, such as better compatibility with the gingiva, greater wear resistance which is particularly helpful when treating pyorrhoea, as well as better color and fit retention.

#### Patent Claims:

1. Dental element, especially a tooth, consisting of a metal base and a preferably multilayered ceramic cap produced from a powdered, feldspar-containing calcination product and a powdered fusion product containing a frit with components of feldspar and of Na<sub>2</sub>O and, where appropriate, MgO, characterized in that the ceramic material of the cap (18, 32, 40, 56) is of the following composition:

SiO <sub>2</sub>	57.8 to 73.0 percent by weight
Al <sub>2</sub> O <sub>3</sub>	11.1 to 17.1 percent by weight
CaO	0.1 to 2.6 percent by weight
MgO	0.1 to 1.8 percent by weight
Na <sub>2</sub> O	1.9 to 9.6 percent by weight
K <sub>2</sub> O	6.35 to 19.3 percent by weight
Li <sub>2</sub> O	0.0 to 5.0 percent by weight

where the expansion coefficient of the ceramic material is selected to be only slightly below that of the respective metal base (12, 34, 48), and that the ceramic material is a homogeneous, baked mixture consisting of

- (a) a vitreous, pulverulent calcination product of a feldspar-containing mineral with an orthoclase of not less than 80% to which, where appropriate, a  $K_2O$ - and/or  $Li_2O$ -containing mineral is added (components # 1, 4, 5 or 6), and
- (b) a powdered fusion product consisting of not less than 30% natural feldspar and a material composed of  $SiO_2$  (5 to 70 percent by weight),  $Al_2O_3$  (0 to 5 percent by weight),  $Na_2O$  (0 to 16.5 percent by weight),  $CaO$  (0 to 5 percent by weight) and  $MgO$  (0 to 3.5 percent by weight) (components # 2, 3 or 7).

2. Dental element as in claim 1, characterized in that the ceramic material is composed of:

$SiO_2$	63	to 73	percent by weight
$Al_2O_3$	14	to 17	percent by weight
$CaO$	0.5	to 1.5	percent by weight
$MgO$	0.2	to 0.8	percent by weight
$Na_2O$	2	to 3.5	percent by weight
$K_2O$	11	to 15	percent by weight

and a homogeneous, baked mixture of

- (a) a vitreous, pulverulent calcination product of a feldspar with an orthoclase of about 80%, with the addition, where appropriate, of 1 to 5%  $K_2O_3$  or a comparable amount of a powdered fusion product consisting of  $K_2O$  and  $Si_2O$  at a 2:5 weight ratio or a powdered frit containing about 50%  $SiO_2$ , 7%  $Al_2O_3$ , 10%  $CaO$ , 5%  $MgO$ , 8%  $Na_2O$  and 20%  $K_2O$  at a (frit:orthoclase-feldspar) weight ratio of 15:85, and
- (b) a powdered fusion product consisting of 70 to 95% natural feldspar and 5 to 40%  $SiO_2$ , preferably of about 75% natural feldspar and about 25%  $SiO_2$ ,

where the ratio between the components (a) and (b) is about 1:1 to 9:1.

- 3. Dental element as in claim 1 or 2, characterized in that the mesial and distal surfaces of the ceramic cap (40) are provided with passages (46) which are filled with the metal of the metal body (48) or with a metal that can be soldered to the latter.
- 4. Method for producing dental elements per claims 1 to 3, characterized in that the ceramic cap is baked in the form of a tooth with a hollow space (41) and that, at a temperature at which the ceramic material is in a plastic state, the metal is poured into the said hollow space.
- 5. Method as in claim 4, characterized in that, before the metal body (48) is cast, the inner surface of the ceramic cap (40) is provided with metal particles such as gold chips.

- ((call-outs, graph, fig. 6:))

Ausdehnungs-Koeffizient	=	Expansion coefficient
der Dental-Porzellane	=	of the dental ceramic materials
Mengenanteile	=	Quantitative proportions
der Porzellan-Komponenten	=	of the ceramic components